Airborne Networks: Beyond Connectivity

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Outline

- Air Traffic Management: ADS-B to Airborne Networks
- Network Connectivity vs. Information Reachability
- Fundamental Performance Measures
- Airborne Network Protocol Design
- Simulation Studies
- Conclusions

Airborne Network Concept

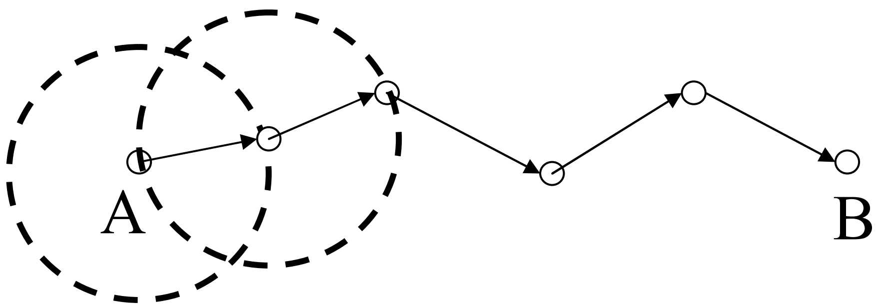
- ADS-B:
  - Each aircraft only broadcasts its own state information
  - Only aircraft within radio transmission range can hear
- Airborne network:
  - Each aircraft periodically broadcasts its own state info as well as relays information for other aircraft;
  - Every aircraft can know every other aircraft's states

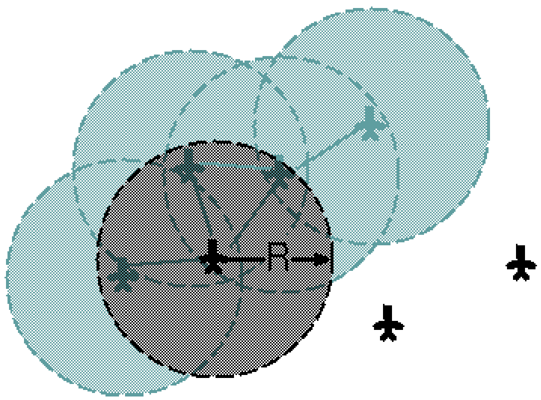
State of the Art in Airborne Networks

- Airborne internet:
  - Broadband, providing email access for passengers
- Future airborne networks:
  - Airborne domain of the Global Information Grid
    - Provide user connectivity to an integrated air, ground, maritime and space network backbone;
    - Provide information routing, protocol translation, security and network management
- Airborne networks for air flight operations
  - Values of airborne networks to air traffic management?
  - Values of airborne networks to UAV operations?
  - What needs to be done?

Airborne Networks for Flight Operation

- Basic requirement: connected





- Previous results:
  - coverage area is increased
  - Connectivity depends on network topology
    - Aircraft position, radio range, antenna direction
    - Independent of network protocols

The Concept of Reachability

- "Connected" Is Not Good Enough
  - It does not provide enough info about network performance
  - Due to collision, info may never reach the destination
    - bottle neck link
  - Due to delay, information may arrive late
    - circular topology: too many hops, but distance short
- Reachability: Info reliably arrives within a specified time
  - Factors that influence reachability
    - Network topology, Network protocols
  - How to measure it?
    - New performance criteria needed
      - specifically, situational awareness

Proposed Performance Measures

- Standalone measures
  - Ratio of reachable/connected: a measure of collision probability
    - The higher the ratio, the lower the collision probability
  - # of reachable in a cluster/# of reachable within one hop
    - Practical gain of using airborne network vs. non-networked schemes
- Situational awareness index
  - Percentage of nodes within a specified range around an aircraft whose state info can be received by the aircraft

    within required time

MAC Protocol Design

- Available MAC design choices:
  - CSMA/CA: Reservation/conformation?

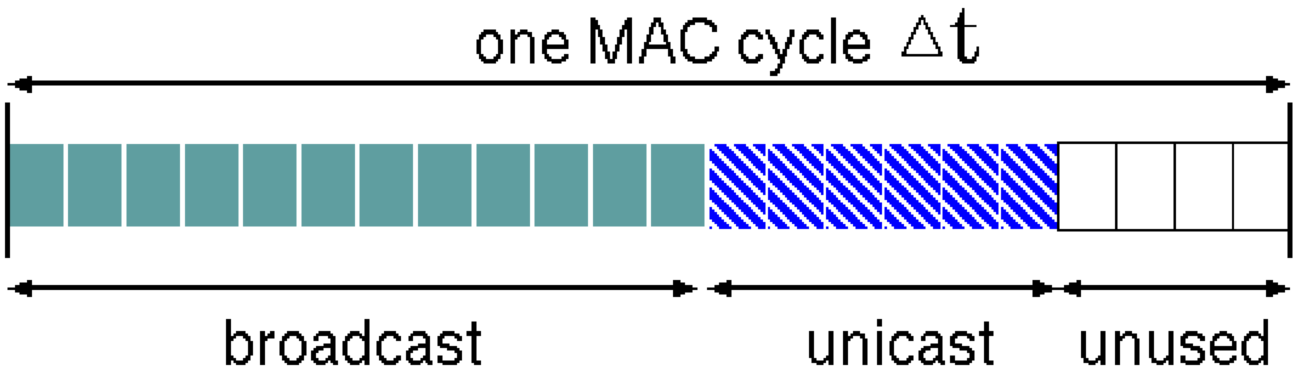
    ➔ not applicable in broadcast
  - CSMA
    - Can not guarantee one transmission per cycle
    - Collision still possible, “hidden terminal problem”

- Proposed: Hash-controlled access with slotted contention window
    - Guarantee one transmission per cycle
    - Collision still possible - Best effort
    - May cause more collisions than CSMA,

      but better information reachability

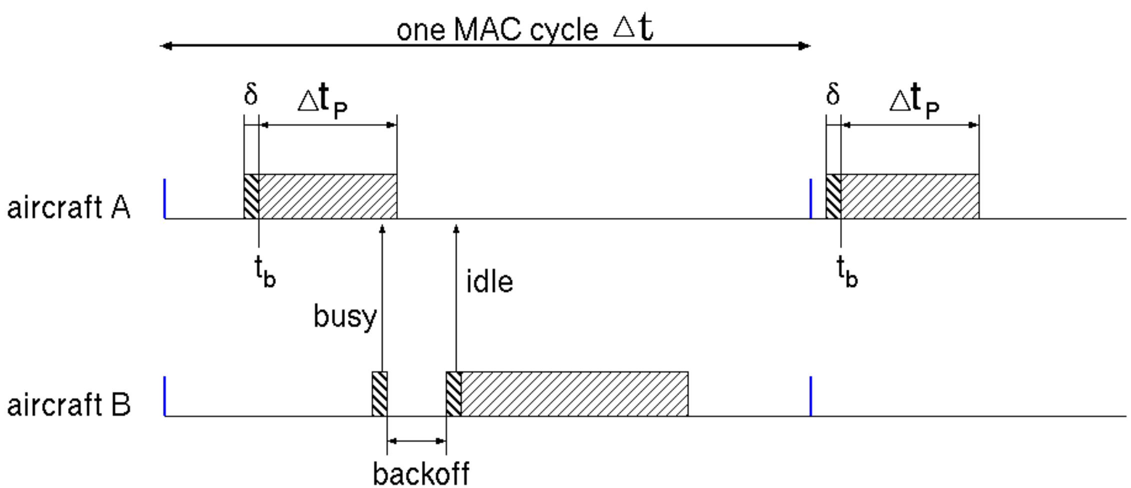
MAC Protocol Design (cont'd)

- Time slots allocation in a MAC cycle
  - Broadcast: state information "flooding"
  - Unicast: point-to-point query/response
  - Reserved: ground communication



MAC Protocol Design (Cont'd)

- Medium Access Scheme:
  Hash-controlled access with slotted contention window:
- Initial wait time and back off time are decided by hash functions.
    - After listening for a δ time
        - idle: transmits
        - busy: transmits with probability p;
            - p increases from 0 to 1 during each cycle



Network Layer Protocol Design

- Relay direction: restricted direction or omni direction
  - correct relay direction may lead to dead end
- Relay distance: unrestricted flooding or bounded flooding
  - Limited hops: May not reachable in limited hops
    ➔ collided on shortest path, but can reach via detoured path
  - unrestricted flooding
    ➔ high collision rate, low reachability
  - Is there an optimal point?

Network Layer Protocol Design (Cont’d)

- Proposed Relay Scheme
  - Limited flooding:

    set TTL to be the maximum # of hops allowed
  - TTL: control parameter,

    dynamically adjusted with traffic density

From Network Layer to MAC Layer

- How long can an aircraft use the channel?
  - packet length is limited for fairness
  - ➔ some packet may be "truncated"

- Should MAC layer transmit everything from upper layer?
  - Regular application data:
    - Will deliver sooner or later
  - Aircraft state information
    - Only useful when it is delivered in time
    - Data generated periodically
      - If not delivered in previous cycle, better forget it and deliver new data

- How to manage the transmission queue?

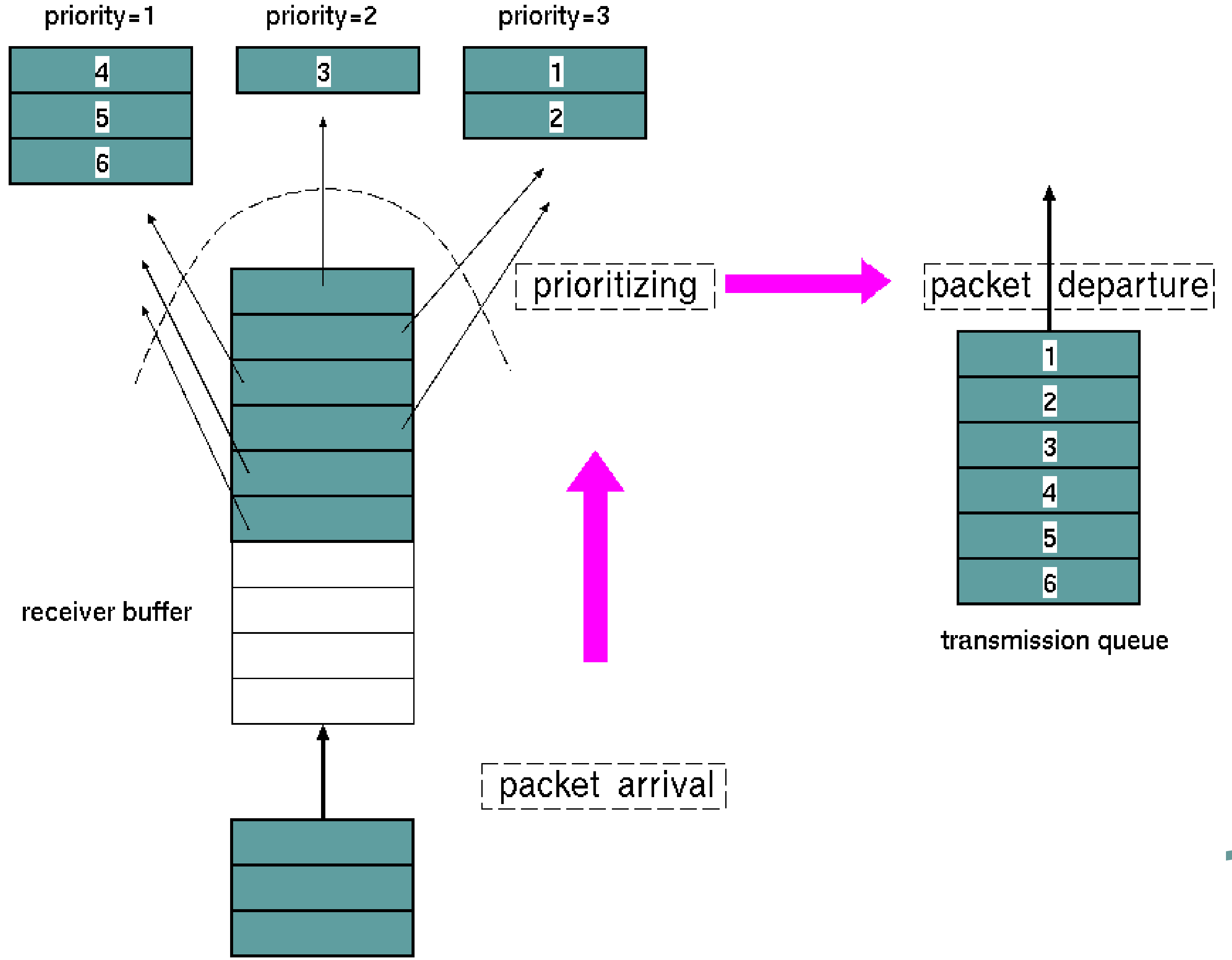
Will a FCFS Queue Work?

- Is a first come first served (FCFS) queue fair?
  - What if one packet is late every time?---starve
  - Some important info may need to be delivered immediately, but it may not be served if a FCFS queue is used
- Need a scheme that can dynamically update the order of items in the queue.

Prioritizing Broadcast Queue

- Assign priority to each record based on distance, urgent level, timestamp, aging factor…
- FCFS order within the same level of priority
- Update priority dynamically

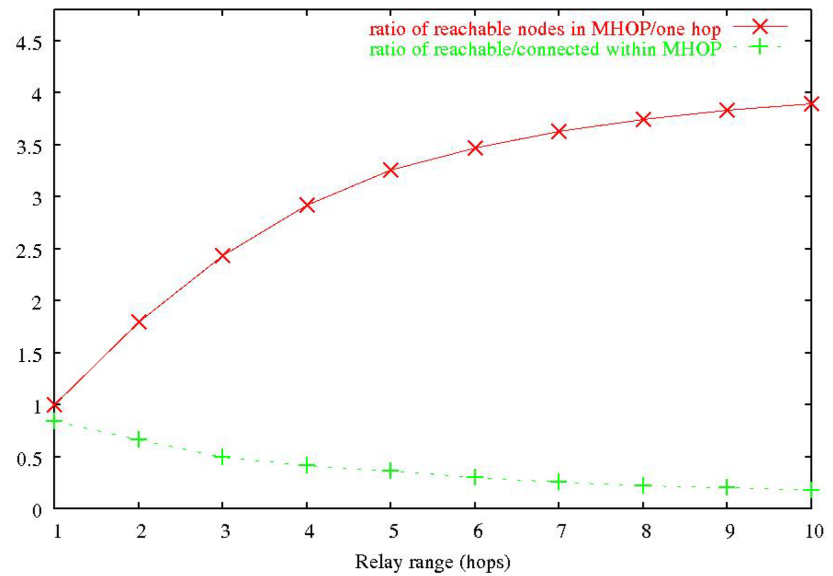
Packet in the Receiving Process



Simulation Results: Scenario 1

- 1D stream of A/C flying with average separation & heading angle
- Aircraft positions deviate from normal positions by small amounts

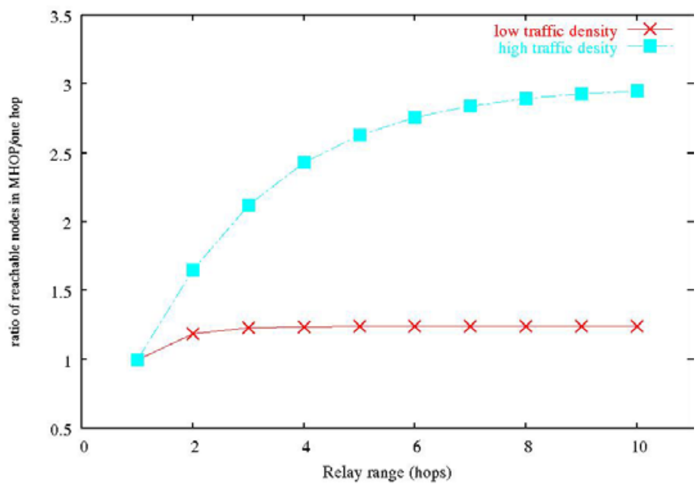
- Reachable nodes through network/ reachable in one hop
  - Increases as flooding range increases
  - Increases slower than linear
- Reachable/connected within MHOP
  - Decreases as flooding range increases



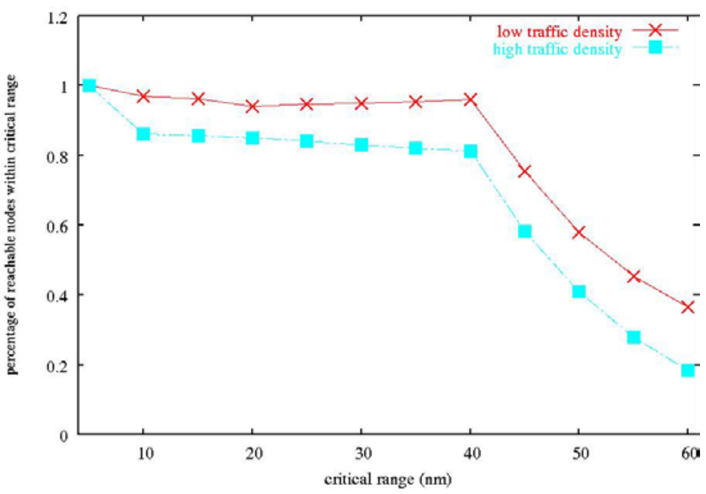
Simulation Results: Scenario 2

- A/C randomly distributed in 2D region; heading angles random also
- Aircraft satisfy minimum separation requirements for flight safety
- Positions updated as the flight progresses

- Reachable through network/reachable in one hop for various hops

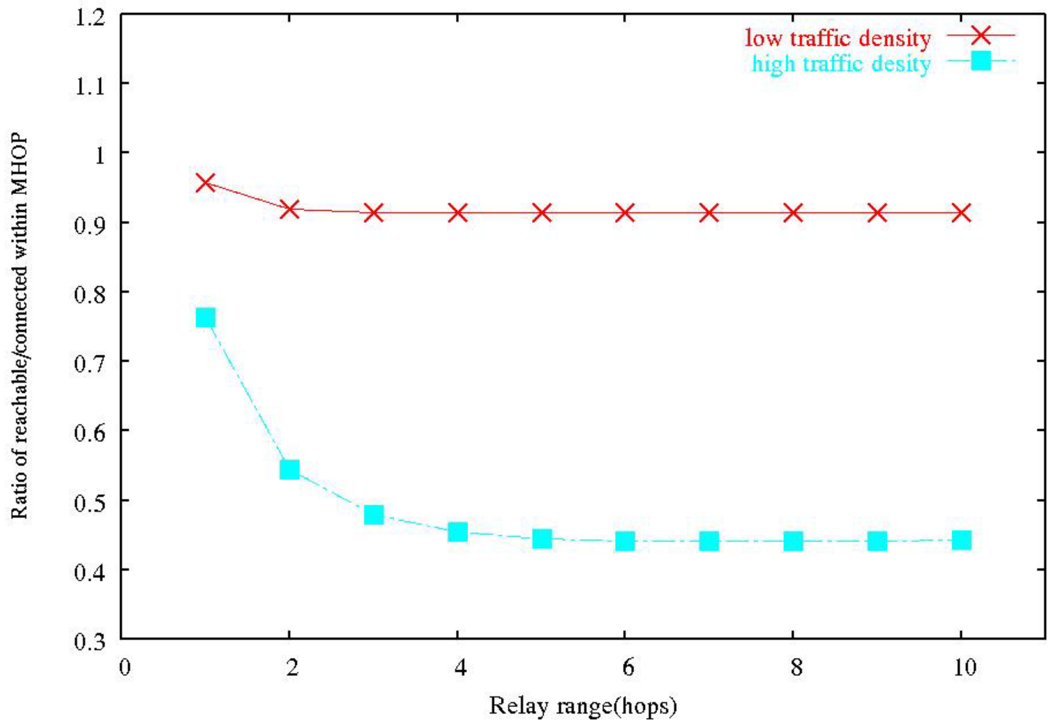


- Reachable nodes/ connected nodes Within critical range



Simulation Results: Scenario 2 (Cont'd)

- # of reachable nodes/# of connected nodes within MHOP



Conclusions

- Information reachability concept & performance measures proposed
- A set of protocols are designed
  - A simple relay scheme can enhance information transmission
  - Medium access scheme: make efficient use of existing radio spectrum
- Simulation studies are conducted.

- Airborne network performance varies with
  - MAC design parameters, relay hops, radio range, traffic density
- Airborne network is shown to provide
  - larger coverage and enhanced information reachability under various simulated traffic scenarios
  - Allows for early safe operation action

Questions?

State Information Packet

- Multiple records in one packet
  - State info for itself
  - One hop neighbors
  - Two hop neighbors
  - …
- Record format
  - Header: Call sign, equipment, TTL, more flag, time stamp.
  - Status information
    - Aircraft state variables
      - Position, velocity
    - intents
      - Acceleration or next way point and time
    - environment variables: wind, pressure, and air density
  - Reserved for future extension

0	16	24	31
call sign	equip	TTL	flag
time stamp			
x			
y			
h			
v_x			
v_y			
v_h			
x_{next}			
y_{next}			
h_{next}			
t_{next}			
$wind_x$			
$wind_y$			
$wind_h$			
pressure			
density			
optional ...			